Fermi National Accelerator Laboratory

FERMILAB-Conf-91/246

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September 1991

* Presented at the *Particles and Fields '91*, University of Vancouver, Vancouver, British Columbia, Canada, August 18-22, 1991.

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CHO3000 with the United States Department of Energy

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ABSTRACT

We will present results from tests of 1.5 m model SSC collider dipole magnets. These R&D magnets are identical to the 15 m full length dipoles currently being assembled at Fermilab in all important aspects except length. Because of their small size they can be built faster and tested more extensively than the long magnets. The model magnets are used to optimize design parameters for, and to indicate the performance which can be expected from, the 15 m magnets. They are instrumented with voltage taps over the first two current blocks for quench localization and with several arrays of strain gauge transducers for the study of mechanical behavior. The stress at the poles of the inner and outer coils is monitored during construction and, along with end force and shell strain, during excitation. Magnetic measurements are made several times during each magnet's lifetime, including at operating temperature and field. We will report on studies of the quench performance, mechanical behavior and magnetic field of these magnets.

The first series of thirteen 50 mm full length collider dipole magnets[1] for the Superconducting Super Collider (SSC) is currently in production at Fermilab and testing is scheduled to begin in October, 1991. A series of 1.5 m model magnets, identical in all important aspects to the 15 m magnets except in length, are also being built at Fermilab.[2] They are used to establish and practice assembly techniques and to provide early data on the performance of the design. Three magnets, DSA321, DSA323 and DSA324, have been tested to date and results of quench performance, mechanical properties and field measurements will be discussed in this paper.

The magnets are instrumented with approximately 50 voltage taps for quench localization during testing. A set of strain gauge transducers are used to monitor the stress at the poles during assembly and cold testing, and the four set screws, which transmit the force from the coil end to the end plate at the return end, are instrumented with gauges to measure this end force.

The interplay between the azimuthal coil size and collar cavity is critical to the performance of these magnets in both quench and field behavior. During excitation the IxB forces reduce the stress at the pole turn and if it drops to zero the coil is said to be unloaded and in a condition where excessive motion is possible. This puts the magnet at risk of quenching due to frictional heating produced by coil slippage. The azimuthal coil size must be adjusted such that they are sufficiently oversize relative to the collar cavity so that sufficient prestress is built into the magnet to provide adequate clamping of the coils up to full field, yet they cannot be so oversize that excessive stress will damage their Kapton insulation.[3] The collar cavity in turn determines the field quality of the magnet and so may require adjustment. The philosophy taken in the model magnet program has been to develop the procedure by which adequate prestress is achieved and thereby develop a mechanically stable magnet. The collar design will then be iterated to provide field quality in the belief that the prestress procedure can be reapplied to this modified collar if necessary.

The target prestress window is 10±2 kpsi on the inner coils and 8±2 kpsi on the outer coils. The prestress on the inner coils of DSA321 were within the desired window, however that of DSA323 was too low. Both the cable vendor and the coil molding procedure changed between the manufacture of these sets of coils and either could be responsible for the drop in coil size. The coils of DSA324 were approximately the same size as those of DSA323 so additional Kapton shim was applied at the poles to increase the stress. Subsequently the coils were manufactured larger by changing the mold dimension.

The model magnets are tested in a vertical dewar over a temperature range of 3.0 to 4.4° K. Measurements of quench current, magnetic field, and pole stress and end force during excitation, are made as well as specialty tests.[4]

Work supported by the U.S. Department of Energy.

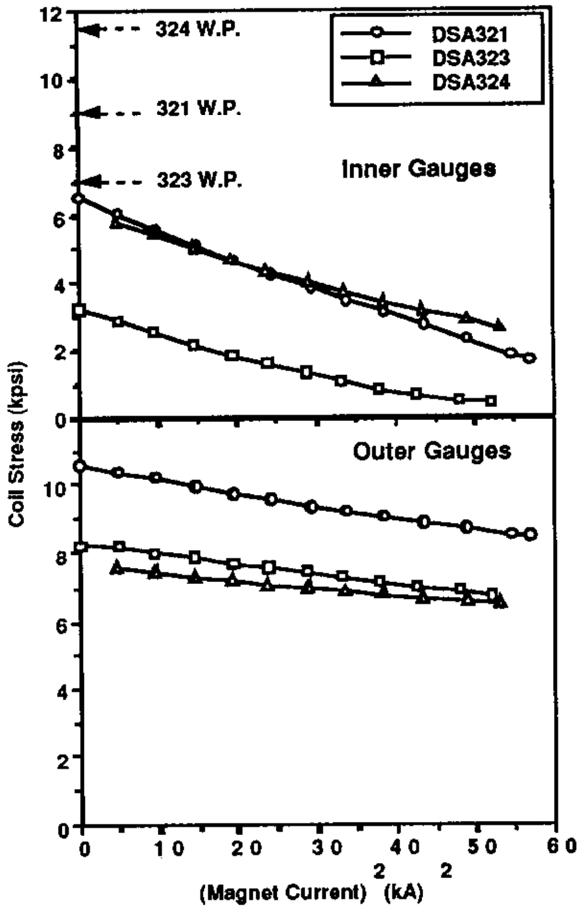

Fig. 1. The inner and outer coil stress versus the excitation current squared after the plateau current has been achieved. The data shown is the average of four gauges. The inner coil warm prestress (W.P.) is also indicated.

Figure 1 displays the inner and outer pole stress for the three magnets as a function of current squared. The warm prestress is also indicated. As can be seen, the stress at the poles of DSA323 is very close to 0 at the operating current of 6.6 kA and was observed to unload at lower temperatures when higher fields were attained. DSA321 and DSA324 did not show any sign of unloading even at the highest fields, giving us confidence that the target warm prestress window which we have set is adequate to maintain prestress at operating field. The outer coil prestress has been higher than desired and since they do not experience as high an IxB force they do not show any sign of unloading in any magnet. Figure 2 displays the quench performance of the three magnets at the three primary temperatures at which they were tested. Only DSA321 showed a training quench significantly below (approximately 500 A) its eventual plateau current at 4.35°K. Even this was well above the operating current of the SSC of 6.6 kA. None of the magnets showed any significant retraining after "thermal cycling" (bringing the magnet to room temperature and then cooling it down again). The only exception to this was DSA324 at 3.8°K during its third thermal cycle. Prior to this thermal cycle the end force had been removed to determine its effect on the performance of the magnet and it is believed that this was the cause of the training. Another run with the end force reestablished is currently in progress to test this hypothesis.

Another important aspect of quench behavior for these magnets is ramp rate dependence. Eddy current heating at high ramp rates tends to decrease the maximum current which the magnets can attain.

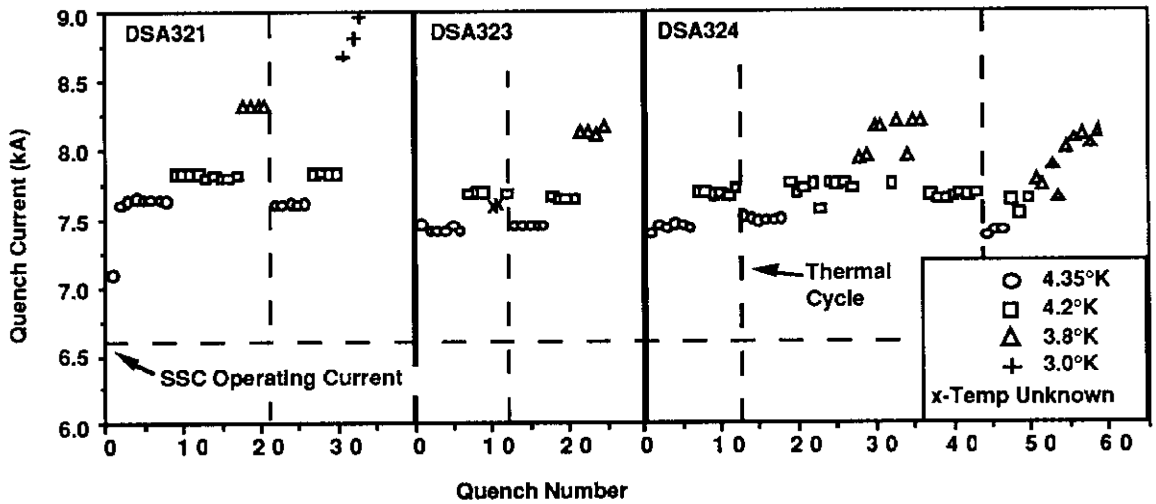

Fig. 2. Model magnet quenches obtained at a ramp rate of 16 A/s.

The level of reduction varies widely between magnets for reasons not entirely understood. None of the magnets tested at Fermilab have shown a decrease at ramp rates less than 25 A/s, well above the rates expected in the SSC. The magnets must also be able to ramp down at rates approaching 400 A/s and DSA321 and DSA324 did not quench when ramped down at this rate. DSA323 intermittently quenched on the down ramp in its return end even at 16 A/s. Two additional thermal cycles, not shown in Fig. 2, were made to investigate this problem and indicated that the quenching was not due to problems in the test setup nor could it be eliminated by increasing the end force loading. The magnet was subsequently disassembled and found to have a gap between the end of its coil saddle and the end can. This may have allowed the coil to slip axially during excitation and de-excitation, leading to the quenches. DSA323 is being reassembled with the gaps filled and will be retested to determine if that was the source of its problem.

A special test was performed on DSA321 in which it was cooled to approximately 3.0°K, the limit of the test facility. The three quenches obtained at this temperature were at fields approaching 9T. The forces at these fields are near the maximum for which the stainless steel collars were designed. That the magnet behaved well at these fields gives us confidence in the structural integrity of the design.

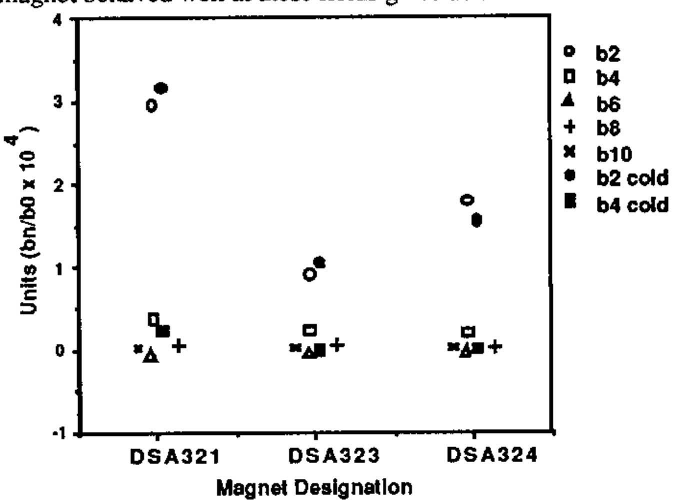

Fig. 3. Warm and cold measurements of allowed harmonics in units of the ratio of the harmonic, (at 1 cm from the center of the aperture), to the dipole field, times 10^4. The multipole component is given by the 2(n+1) where n is the subscript of b (e.g. b_2 is the sextupole component).

Magnetic field measurements are made at several times during the assembly of the magnets.[5] Figure 3 compares the allowed multipole components (i.e. those caused by geometric imperfections which do not cause up-down or left-right asymmetries in the current distribution) for the yoked magnets as measured at room temperature with 10 A flowing through the coils and (for b_2 and b_4) cold with 5 kA flowing. The sextupole component is very sensitive to variations in the pole position of the coil and in variations in the cable distribution within the coil, so it is not unexpected to see variations in b_2 among these magnets. The data indicate that only minor tuning of the coil geometry will be necessary to bring the field within specification for the SSC. The unallowed harmonics, measured warm, also appear to be acceptable.

In summary, three 50 mm SSC model dipoles have been built and tested at Fermilab. The quench and mechanical performance of these magnets is very good. The field quality is also satisfactory and only minor tuning should be required to bring the magnets into specification for use with the SSC.

We would like to acknowledge the work of the many engineers and technicians whose efforts made possible the results presented in this paper.

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[1] J. Strait et al., Mechanical Design of the 2D Cross-section of the SSC Collider Dipole Magnet, submitted to the Proceedings of the 1991 Particle Accelerator Conference, 1991; R.C. Gupta, et al., SSC 50 mm Dipole Cross Section, submitted to the 3rd International Industrial Symposium on the Super Collider, Atlanta, GA, March 13-15, 1991.

[2] R.C. Bossert et al., Construction Experiences with SSC Collider Dipole Magnets at Fermilab, submitted to the Proceedings of the 12th International Conference on Magnet Technology, 1991.

[3] J. Strait et al., Mechanical Behavior of Fermilab-Built 1.5 m Model SSC Collider Dipoles, submitted to the Proceedings of the 12th International Conference on Magnet Technology, 1991.

[4] M. Wake et al., Tests of 1.5 Meter Model 50 mm SSC Collider Dipoles at Fermilab, submitted to the Proceedings of the 1991 Particle Accelerator Conference, 1991.

[5] M.J. Lamm et al., Magnetic Field Measurements of 1.5 Meter Model SSC Collider Dipole Magnets at Fermilab, submitted to the Proceedings of the 12th International Conference on Magnet Technology, 1991.